

temperatures," which is based upon a series of maps published in paper (1) indicates for this portion of the United States the amount of variation, month by month, from the average temperature round the world in similar latitudes. This average temperature in similar latitudes measures air temperatures as a function of latitude; variations from average temperatures—i. e., anomalous temperatures—indicate the local temperature variations of the United States due to the effect of the sun upon the area of the northeastern United States. Consequently figure 1 shows that the rainfall of this area depends (1) upon the elevation of the sun, and (2) upon the world position of the area in particular reference to the swing of the sun. Figures 6 and 7 indicate the areas of differences in the driest and wettest periods, respectively, and give a spatial meaning to the facts shown in figure 1.

Consideration of the twelve monthly maps presented by figures 2, 3, 4, and 5 leads to a division of the northeastern United States into four rainfall regions—(1) the northeast corner which bears little relationship to the remainder of the area and can be omitted from further consideration; (2) the Lake region and Michigan on the north; (3) the Ohio Valley area in the middle, and (4) the Piedmont and the Coastal area on the southeast. It is convenient to begin the examination of the maps with the month of September. In that month the north (2) and the coast (4) are of average wetness, but the Ohio Valley (3) is relatively dry. In October the dryness is more extensive and reaches almost to the southeast [the South Atlantic] coast. In November the dry conditions have moved still farther eastward. In December the rainfall is very little removed from normal (100 per cent) everywhere. In January the Ohio Valley is wetter than the neighboring hills, and beyond the hills there is a still drier region. In February the coastal lands are wet and the north is dry. In March the Ohio Valley shows signs of greater wetness, which persists during April.

In May the north is the wettest region; this relative wetness spreads eastward by June and becomes more intense by July. In August the wetness has reached the coast. The maps, therefore, give a spatial significance to the conclusions previously stated, which may be generalized thus: A wave of dryness moves southeastward during the period when the temperature is falling, from September to the end of January, and a wave of wetness moves southeastward during the period when the temperature is rising, from May to August.

The rainfall of the northeastern United States is a function of its latitude and its position on the western margin of the Atlantic Ocean.

II.

THE DISTRIBUTION OF THE RAINFALL IN THE EASTERN UNITED STATES.

By B. C. WALLIS, B. Sc. (Economics), F. R. G. S., F. S. S.

[Dated: North Finchley, England, Nov. 24, 1914.]

In the preceding paper the sequence of the intensity of the rainfall was described in reference to the northeastern corner of the United States. This area includes the major portion of the industrial area of the United States and is a region of diverse farming operations; in the present communication the area which includes the cotton belt and the greater portion of the wheat belt has been added to the

area previously described, and the rainfall of the whole area is now considered in a broader view and with less detail than was possible in regard to the northeast. The method of calculating pluviometric coefficients has already been described, so that it is possible to pass at once to the statement of the conclusions to be drawn from the accompanying maps and diagrams (figs. 6–23).

It should be noted, first, that the range of the rainfall intensity is much greater in the area now considered than in the northeast alone. The minimum value of the pluviometric coefficients is less than 33 and the maximum is between 200 and 233 which gives a range of 200 equivalent to one-sixth of the total annual precipitation. In the northeast corner the range extends from 70 to about 150, and is less than 100, i. e., less than the rainfall norm for one month. A general survey of the twelve monthly equipluvial maps (figs. 12–23) at once forces the conclusion that, in general, the rainfall gradient is from northwest to southeast, for the majority of the equipluvies run from northeast toward the southwest. This fact was suggested by the conclusions reached in the above communication.

The main features of the intensity of precipitation may now be considered month by month. In January (fig. 12) rainfall slightly above the norm occurs in the valleys of the lower Mississippi and the Ohio; to the southeast and to the northwest the intensity of rainfall diminishes. In February the area of rainfall above the norm has extended toward the coast and in Alabama and Georgia the rainfall is most intense; elsewhere there is little change from January. In March, except for an increased intensity in the Dakotas and along the coastal lowlands near Chesapeake Bay there is slight change from February.

In April, west of the Mississippi, the rainfall is above the norm, and the area east of that river tends to be drier. In May there is a marked increase in the intensity of the rainfall especially in Oklahoma and South Dakota; in general, the intensity of the rainfall increases with the distance from Florida. In June the southeast coast States and the northwest States show a marked increase in intensity; from the Dakotas to Kansas, the rainfall is at the maximum for the whole area, the fall in June being equal to twice the norm. Alabama has the least intense rainfall and the month in general is the exact opposite of January and February.

In July the whole intensity seems to have moved toward the northwest, the coasts are wetter and the northeast is drier than in June. In Belt I (fig. 8 and 9) the rainfall intensity "swings with the sun," and the farther away the land lies from the ocean, the more precisely is this fact true. About the seasons of the equinoxes the rainfall is the norm, at midwinter low, and at midsummer it is high; the pluviometric range is very large. In Belt II (fig. 8 and 10), in general, the pluviometric range is least; the most striking feature of the diagram is the way in which the graphs interlace. On a very small scale the rainfall of this belt varies with the "swing of the sun." The whole of this belt is marked by a comparative steadiness of the precipitation throughout the year; it forms a striking illustration of the phrase "rainfall at all seasons." In Belt III (fig. 8 and 11), the pluviometric range is intermediate between those in the other two belts and the distribution of the rain is unequal. From November to July, i. e., about two-thirds of the year, the rainfall intensity increases by two stages which are separated by a slight fall near the spring equinox. The intensity drops suddenly from August to November.



FIG. 6.—Map of the driest months in the eastern United States.



FIG. 7.—Map of the wettest months in the eastern United States.



FIG. 8.—Map of the rainfall regions of the eastern United States.

RAINFALL INTENSITY AND TEMPERATURE.

It will be well for a moment to consider the relation between the observed facts and the temperature conditions which prevail in general in the eastern half of the United States.

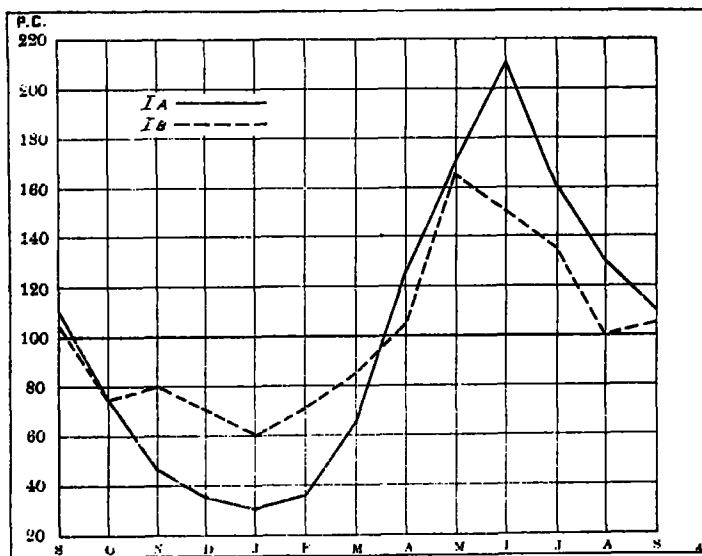


FIG. 9.—Annual march of rainfall intensity in Rainfall Regions IA and IB. (See fig. 8.) P. C.—pluviometric coefficients.

Temperature may be considered from two points of view:

- (1) The normal temperature for the latitude of a place;
- (2) The abnormal variations in different months which separate areas experience as a result of definite local conditions.

Normally the temperature of a latitude "swings with the sun," consequently in the northwest corner of our district (IA on figs. 8 and 9) intensity of the rainfall varies directly with the normal temperature.⁴ The gradient of this normal temperature runs from south to north, consequently the rainfall in general over the whole area does not vary in intensity in simple relation to the temperature. Various areas are affected by the abnormal [or anomalous] temperatures. In the United States the zero isanomalous line (or isanomal), i. e., the line along which actual temperatures agree with the latitude normals, runs in January toward the northwest from Florida, with an abnormally cold area to the northeast and an abnormally warm area to the west. This zero isanomal maintains this position from December until April, i. e., during the whole of the period when frosts are possible. From April to October this zero line is shifted bodily toward the northeast, so that the area of abnormal (anomalous) warmth covers an increasingly large portion of the United States; in August, when this area is largest and also warmest it covers practically the whole of the United States.

It follows then from this fact that the movement of the date of maximum rainfall from June to August (fig. 7) agrees with the gradual spread, in the same direction, of an area of abnormal (anomalous) warmth, so that the delay of the season of maximum rainfall intensity until it is later than the period of maximum elevation of the sun accompanies this delay in the autumnal fall in air temperature.

The zero isanomal swings back to its January position by October and beyond it in November, so that in November practically the whole of the eastern half of the United

⁴ The author uses this term here in the sense of "the normal temperature of the given parallel of latitude" as that expression is used in Ward's translation of Hann's *Handbuch der Klimatologie*, 2d ed. New York, 1903, p. 199. See the paper under (1) where is given a table of monthly normals for latitudes and monthly charts of isobnormals for the world.—[C. A. J.]

States is abnormally cold; the temperature drop in this region is, therefore, specially rapid from September to November. In August there is everywhere a general tendency to a decline in intensity from the previous month. In September the drop denoted for August becomes more marked except near the borders of Mexico. In October the eastern United States is in general drier than in September.

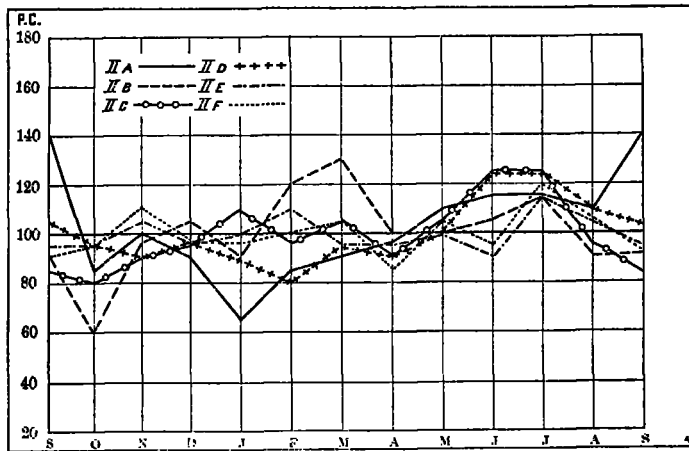


FIG. 10.—Annual march of rainfall intensity in Rainfall Regions IIA-III F. (See fig. 8.) P. C.=pluviometric coefficients.

In November it seems as if the whole intensity of the rainfall had moved toward the southeast, the exact opposite of May. In December there is a further movement toward the southeast. In general, when the temperature is increasing, rainfall intensity increases in all directions from Alabama and Mississippi, and conversely when the temperature is decreasing.

The general conclusions which may be drawn from these 12 maps are indicated on the maps forming figures 6-8. Figure 6 shows that except in the extreme northeast the driest month varies in three broad bands

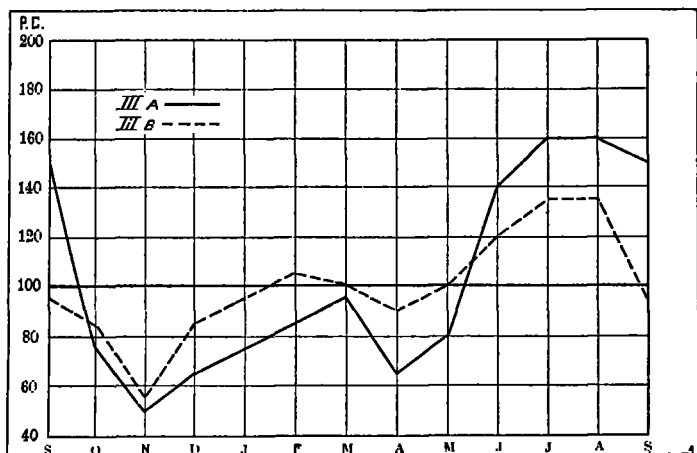


FIG. 11.—Annual march of rainfall intensity in Rainfall Regions IIIA-III B. (See fig. 8.) P. C.=pluviometric coefficients.

stretching across the general pluviometric gradient. On the northwest, January, in the Mississippi and Ohio valleys, October, and along the coast November is the driest month. Figure 7 shows that, in general, the three broad bands persist with a subdivision of the middle band; so that with the exception of Tennessee, Alabama, etc., the date of maximum rainfall tends to become later

as the coast is approached from the northwest. Figure 8 results from an attempt to distinguish various rainfall regions based upon the foregoing observations. The northwest and the coastal bands are divided into two areas, and the middle band—including the northeast corner—is divided into six separate areas.

The details of the variation in intensity month by month are shown in figures 9-11, which should be studied in connection with the maps of figures 12-23.

Only in November is the temperature of the coast lands abnormally low and this fact is connected with the minimum rainfall intensity of Belt III (figs. 8 and 11) in that month. It should also be pointed out that in general the isanomalous lines of $+5^{\circ}\text{F.}$ and -5°F. coincide in direction with that of the pluviometric gradient.

In sum, it may be concluded with regard to the rainfall Belts I and II (see fig. 8) that their rainfall intensity depends upon temperature, and varies directly with the temperature. When the temperature is anomalous, the rainfall is anomalous, i. e., it varies from the standard rainfall which may be indicated by such a graph as Ia of figure 9.

The anomalous temperatures which occur in the atmosphere are chiefly due to proximity to the oceans, so that the rainfall of Belt III, figure 8, is profoundly affected by the nearness of this belt to the Atlantic Ocean. Inland from the coast the effect of the ocean diminishes, coastward from the Dakotas the effect of the continental land mass diminishes, and the net result of these two facts is seen in the rainfall of Belt II where the interlacing of the graphs in figure 10 is evidence of the clash between the causes which govern the intensity of the rainfall. It is possible in many cases to connect the slight fluctuations in the intensity of the rainfall, as shown in figure 10, with the fluctuations in anomalous temperature; e. g., the average rainfall intensity of November and December (P. C. 100, fig. 10) is connected with the fact that the zero isanomal, which separates the anomalously warm air of the Atlantic Ocean from the anomalously cold air of the Hudson Bay area, coincides with Belt II in figure 8. Finally the total annual rainfall of the eastern half of the United States decreases in general with the distance from Florida, i. e., with distance from the sea.

SUMMARY.

In fine, the rainfall intensity as well as the actual amount of precipitation of the eastern United States depends upon three separate factors:

- (1) The "swing of the sun," which has its most marked effect at places farthest from the sea;
- (2) The local variations in temperature which give rise to abnormal temperature conditions, which have their most marked effect in causing variations in the months of maximum and minimum intensity of rainfall;
- (3) The proximity of the ocean which causes heavy total precipitation near the coast and masks to some degree the effect of insolation.

Thus, there are the three rainfall belts shown by figure 8, viz:

- I, a belt of summer rains and winter dryness;
- II, a belt of rainfall at all seasons, due to the middle position of the area between the continental conditions of Belt I and the oceanic conditions of Belt III;
- III, a belt of masked summer rains.

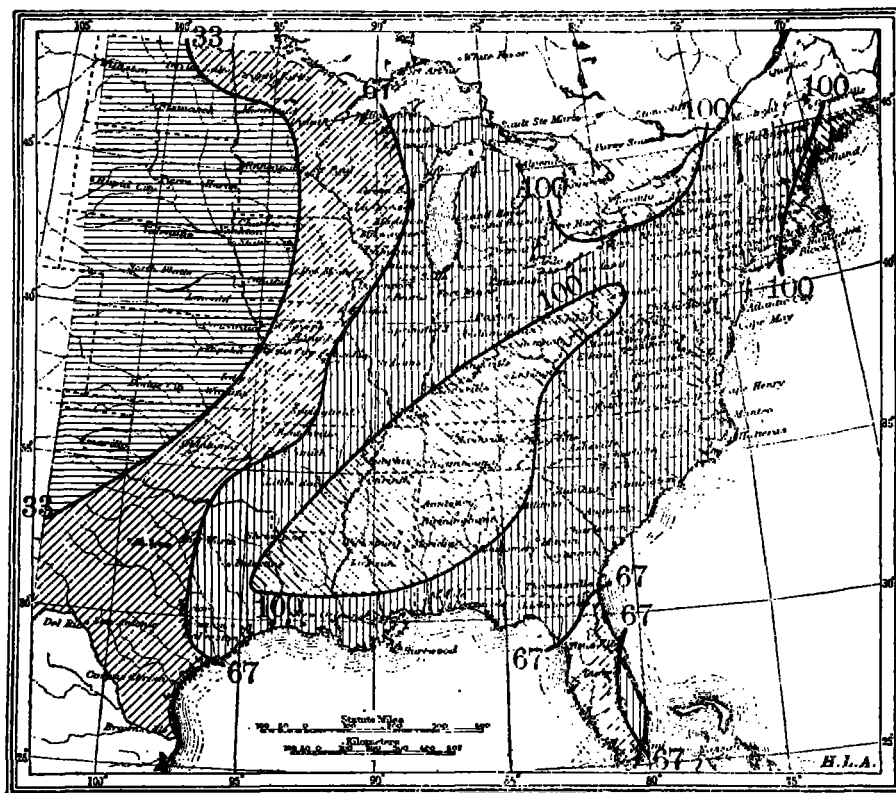


FIG. 12.—Isotherms for the eastern United States for January.

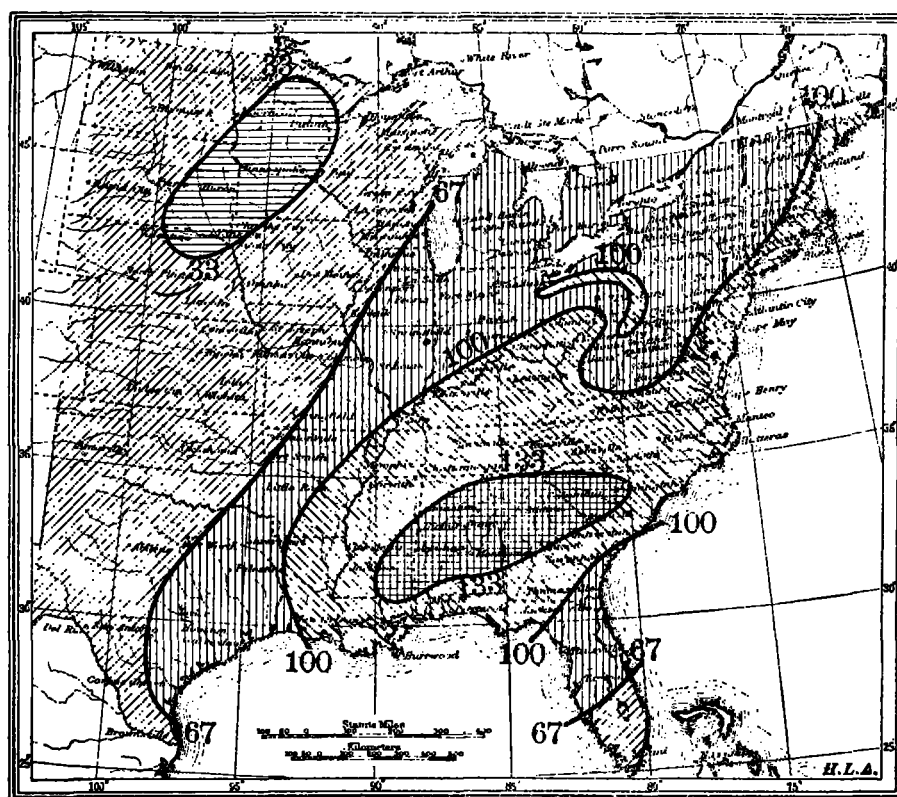


FIG. 13.—Isotherms for the eastern United States for February.

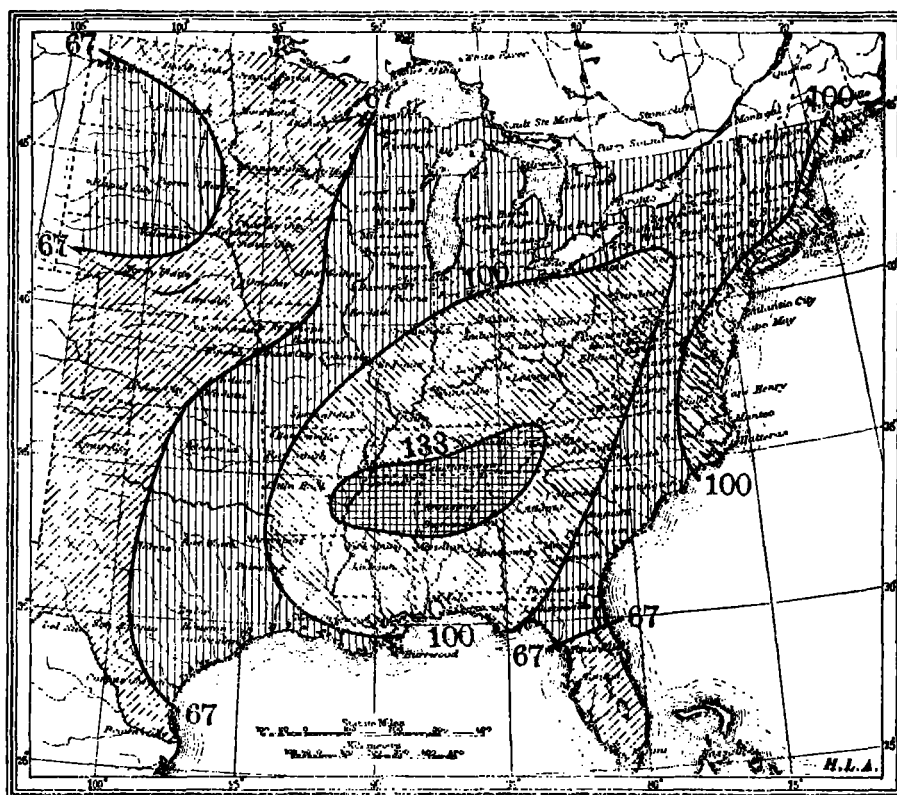


FIG. 14.—Equipluvets for the eastern United States for March.

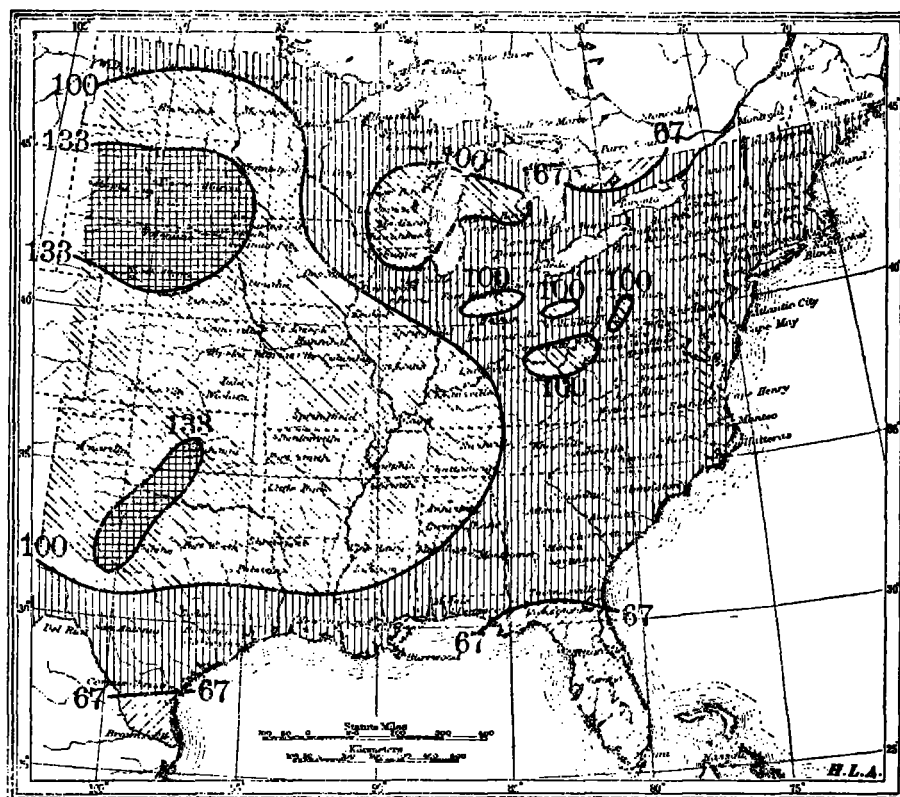


FIG. 15.—Equipluvets for the eastern United States for April.

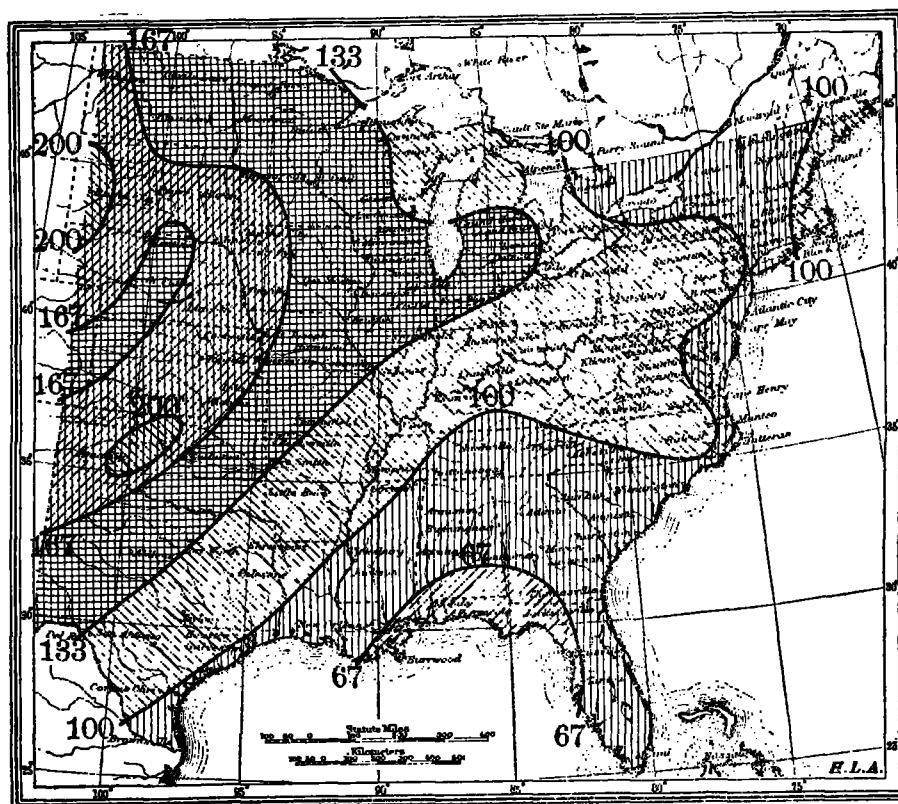


FIG. 16.—Equipluvets for the eastern United States for May.

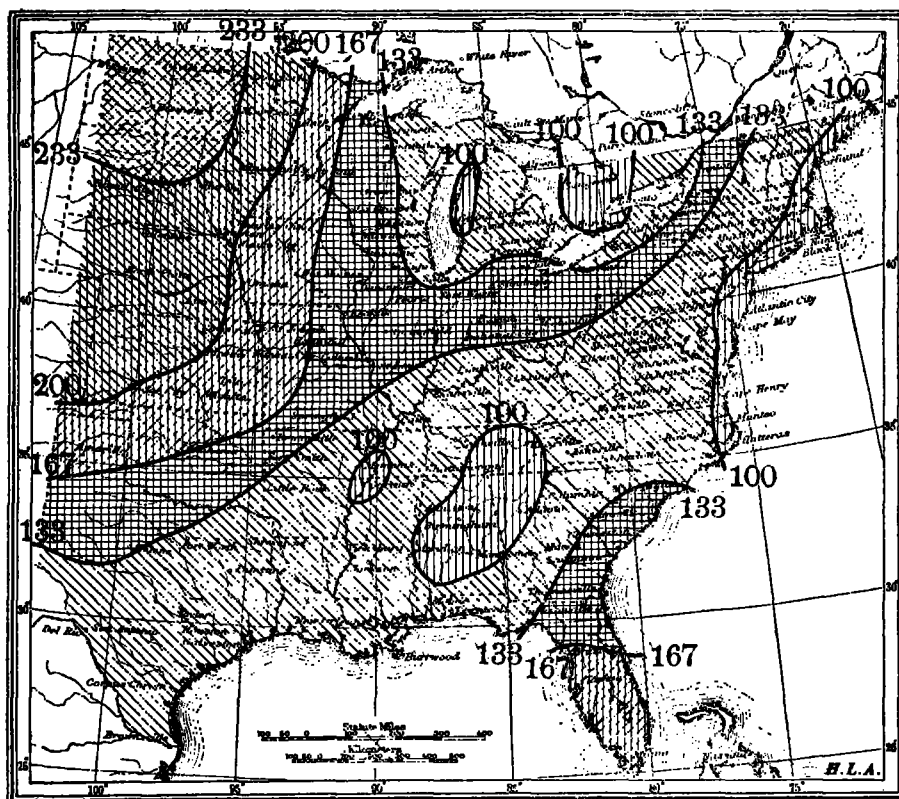


FIG. 17.—Equipluvets for the eastern United States for June.

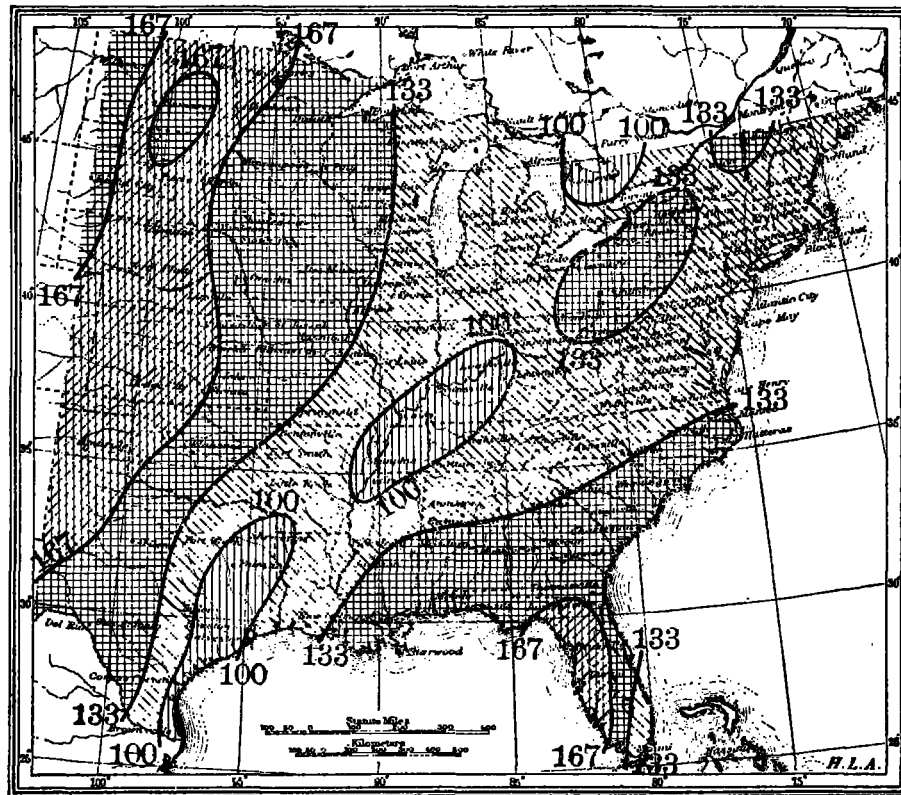


FIG. 18.—Equipluvets for the eastern United States for July.

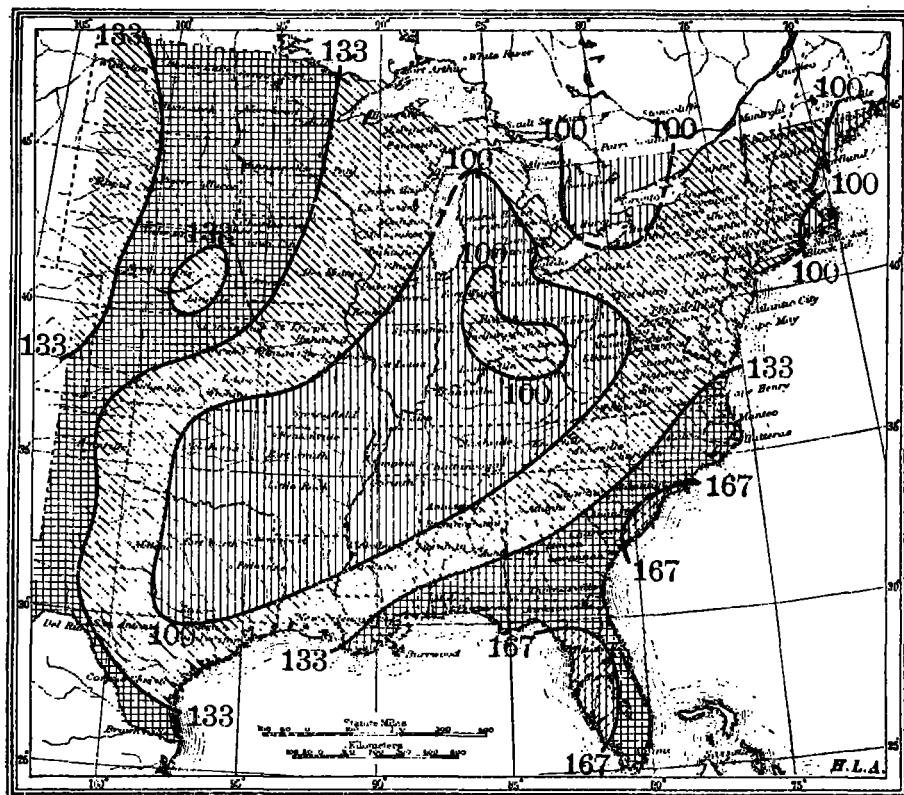


FIG. 19.—Equipluvets for the eastern United States for August.

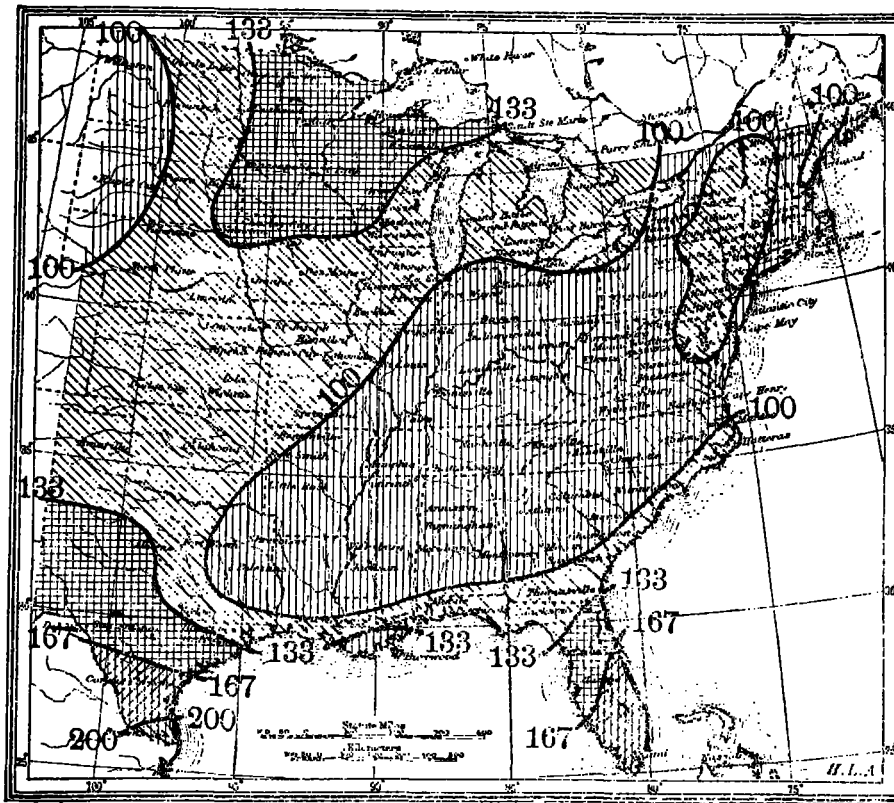


FIG. 20.—Equipluvets for the eastern United States for September.

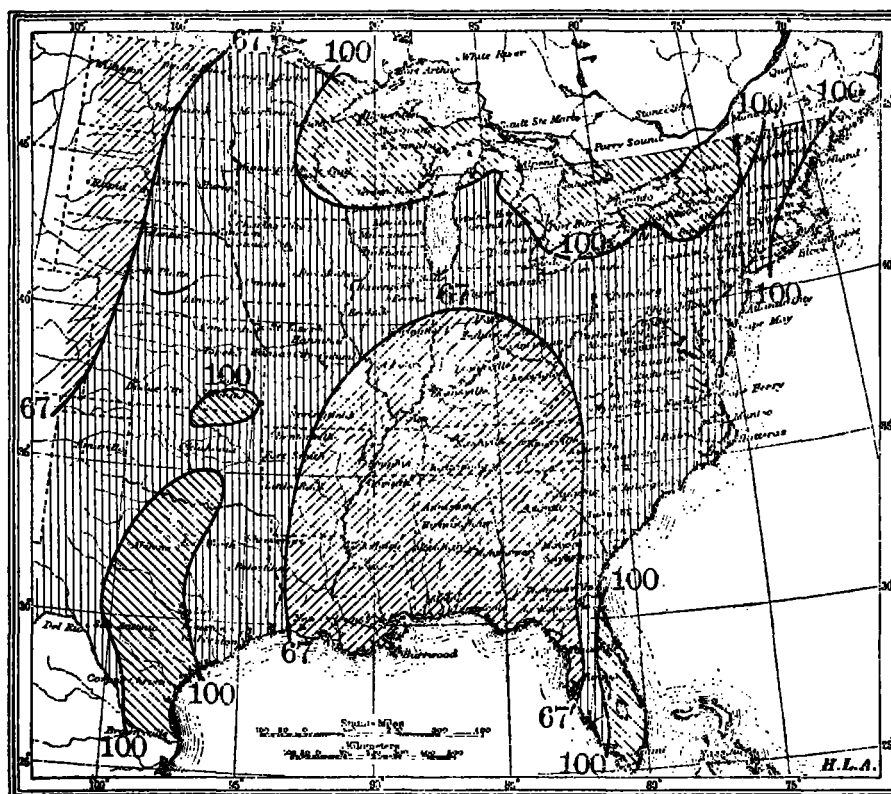


FIG. 21.—Equipluvets for the eastern United States for October.

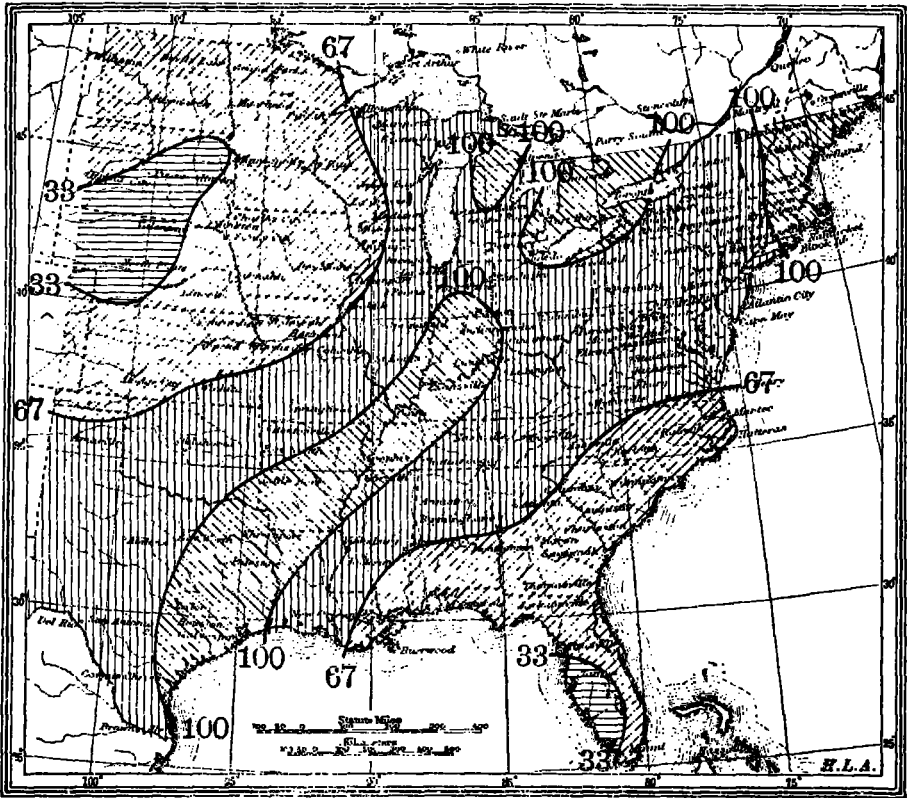


FIG. 22.—Isotherms for the eastern United States for November.

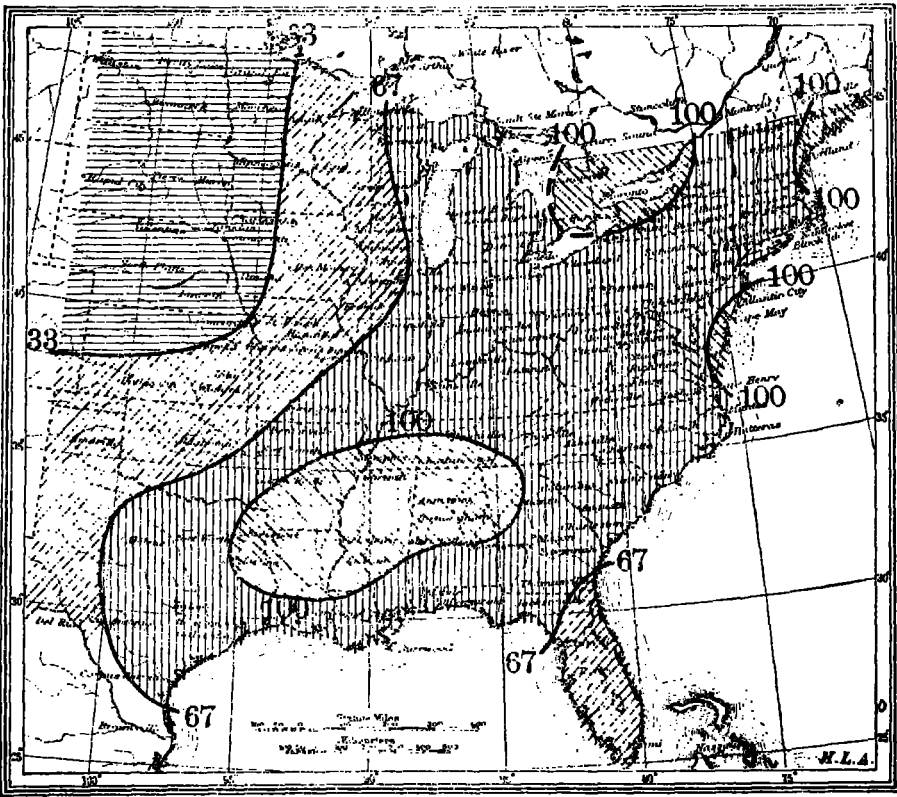


FIG. 23.—Isotherms for the eastern United States for December.

REFERENCES.

- (1) Wallis, B. C. Geographical aspects of climatological investigations. *Scott. geogr. mag.*, Edinburgh, July, 1914, 30: 356-369.
- (2) Wallis, B. C. The rainfall régime of Australia. *Scott. geogr. mag.*, Edinburgh, Oct., 1914, 30: 527-532.
- (3) Wallis, B. C. The rainfall of the southern Pennines. *Quarterly jour., Royal metl. soc.*, London, October, 1914, 40: 311-326.
- (4) Discussion of (3) above, pp. 323-325.

"MONSOON" RAINFALL.¹

By B. C. WALLIS, North Finchley, England.

The total volume of the precipitation in certain parts of India is apparently so extraordinary that it has caught the special attention of geographers and teachers, and the term "monsoon" rainfall has tended to imply a very special type of rainfall which is intimately related to the southwest monsoon wind. Later investigations demonstrated the fact that the Abyssinian rainfall which caused the Nile flood was sufficiently similar to the Indian rainfall to be called "monsoon" rainfall. The summer rainfall in Abyssinia * * * [has an intensity of 300 per cent] agreeing with a general high rainfall intensity which is reached by those places which have vertical sunshine when the sun is, as it were, journeying southward from the Tropic of Cancer. The rainfall intensity lags behind the sun, so that at a certain place south of lat. 23½°N. the maximum intensity which has been following the sun northward is reinforced by the sun's second passage through the zenith. A precisely similar phenomenon is to be noted in the Southern Hemisphere just north of the Tropic of Capricorn.

Now the pluviometric coefficients for Indian rainfall tend to show precisely the same magnitude of rainfall intensity during the same months as in northern Africa. A rough glance at the monthly and annual rainfall maps of the world in [Bartholomew's] Atlas of Meteorology shows a similar rainfall intensity in northern Australia—where the term "monsoon" rains is used—and also in the belts of similar latitude in South America.

Hence it follows that the maps [published in the original whence this is excerpted] lay bare one of the factors in connection with monsoon rains in India; the incidence of rainfall intensity [as expressed by Angot's "pluviometric coefficients"] is a question of latitude and is a world phenomenon, not a purely local Indian fact. "Monsoon" rainfall, as the name of a phenomenon which is most typically exemplified in India, refers entirely, when regarded in relation to the southwest monsoon, to the *quantity* of the rainfall and not to its incidence during the summer months. Quantity of precipitation appears, therefore, to be a matter of *local* importance due to elevation, prevailing winds, and nearness to the sea as well as to the average temperature of the air.

Eastern Asia and eastern America.—It is usual to extend the term "monsoon rainfall" to include the summer rains of northern China and southern Japan. A similar investigation to that of the preceding paragraph indicates that the summer rains of these portions of eastern Asia resemble in incidence of intensity, but not in total quantity, the rainfall which is characteristic in areas of similar latitude to the northeast of the United States.

Here, again, the term "monsoon" is applicable to quantities of rain which coincide in period with the on-shore winds of the monsoon; and this fact is related to

the special nature of the temperature changes to which reference has been made in the first section of this paper.²

Summer savanna rainfall.—Summer savanna rainfall in the Sudan and Rhodesia is * * * almost entirely a question of (a) a small total annual precipitation and (b) a high summer rainfall intensity which is a question of latitude in relation to the force of solar radiation; and apart from the smaller amount of the total annual precipitation summer savanna rainfall is equivalent to "monsoon" rainfall.

ON THE USE OF "AVERAGE," "MEAN," "GENERAL."¹

By HUGH R. MILL, London.

In considering the distribution of rainfall * * * we need to use terms with a definite meaning, and I hope that I may be excused for assigning definite meanings to familiar English words instead of importing classical terms which, despite a grander display of syllables, can mean no more. For convenience I use the term *mean* as indicating the sum of any number of figures divided by that number, reserving the word *average* for the mean of a number of figures representing values in order of time. Thus the mean of 30 annual rainfall values is spoken of as the average rainfall for 30 years. The mean of a number of uniformly distributed figures representing the distribution of rainfall in space I speak of as the *general* rainfall of the area concerned; thus the mean depth of rainfall over England for any day, month, or year is the *general rainfall* of England for that particular day, month, or year. The mean of the general rainfall of England for 30 years is expressed as the *average general rainfall* of England for 30 years. A line passing through points having the same rainfall is an isohyetal line, or *isohyet*—the term having been already introduced is retained on account of its similarity to isotherm and isobar. The line joining successive positions of the center of an atmospheric depression or cyclone is the *track* of the depression. The isohyetal lines representing the distribution of rainfall in a shower may be termed the *splash* of the rainfall, and the isohyets representing the rainfall of one or several days for a considerable stretch of country along the track of a depression, which is the generalization of a succession of splashes, may be called the *smear* of the rainfall of that depression.

TEMPERATURE AND SPRING WHEAT IN THE DAKOTAS.

By THOMAS A. BLAIR, Observer.

[Dated, Weather Bureau, Wagon Wheel Gap, Colo., Jan. 8, 1915.]

In a previous article (1) a short study was made of the relation between rainfall and the yield of wheat in the great northwestern spring-wheat region comprising the States of Minnesota, North Dakota, and South Dakota; and the conclusion reached that the total precipitation of May and June, without regard to its distribution, is, in most years, the most important factor in determining the yield in the two Dakotas, but not in Minnesota. At the same time, attention was called to the fact that there is an evident relation between temperature and yield. A further study of this relation leads me to modify the above conclusion so far as to state that the mean temperature of June exercises an equally important influence on the yield in the Dakotas.

² Wallis, B. C., op. cit., p. 356-363.

¹ Extracted from [H. R. MILL]. On mapping rainfall. *British Rainfall*, 1907. London, 1908. 47: 36-43.
See also H. R. MILL. Map studies of rainfall. *Quart. jour. Royal metl. soc.*, London, No. 146, April, 1908, 34.

¹ Extracted from B. C. Wallis. Geographical aspects of climatological investigations. *Scott. geogr. mag.*, Edinburgh, July, 1914, 30: (365, 368-369).